Dynamic Leadership for Human-Robot Teams

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ABSTRACT

This paper evaluates collaborative tasking tools that facilitate dynamic sharing of responsibilities between robot and operator throughout a search and detection task Participants who utilize Collaborative Tasking Mode (CTM) do not experience a significant performance penalty, yet benefit from reduced workload and fewer instances of confusion. In addition, CTM participants report a higher overall feeling of control as compared to those using Standard Shared Mode.

Categories & Subject Descriptors

I.2.9 [**Artificial Intelligence**]: Robotics – *Autonomous Vehicles, Operator Interfaces*

General Terms

Experimentation, Human Factors, Performance

1. INTRODUCTION

Idaho National Laboratory (INL) has conducted a series of experiments over the past several years aimed at exploring the rich middle ground between direct human control and full robot autonomy [1, 2]. In this experiment a real-world search and detection experiment is used to compare Standard Shared Mode (SSM), where the robot drives, but the human can override the robot at any time, to a Collaborative Tasking Mode (CTM), where the system dynamically constrains user and robot initiative based on the task element. In SSM, overall team performance may benefit from the robot's understanding of the environment, but can suffer because the robot does not have insight into the task or the user's intentions. As a result, the human must override the robot, which reduces efficiency, increases human workload and may also increase user distrust or confusion. Instead, the CTM interface tools provide the human with a means to communicate information about the task goals. Although CTM does support high level tasking, the benefit of the collaborative tasking tools is not merely increased autonomy, but rather the fact that they permit the human and robot to mesh their understanding of the environment and task. Based on this combined understanding of the environment and task, CTM is able to arbitrate responsibility and authority.

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2. EXPERIMENT

The experiment was set up as a remote deployment such that the operator control station was located several stories above the robot arena so that the operator could not see the robot or the operational environment. The production staff of the Science Center used plywood dividers and a variety of objects such as artificial rocks and trees to create a 50ft x 50ft environment with over 2000 square feet of navigable space. Each participant was given basic instructions on how to use the interface, and no participants were permitted to control the robot prior to the start of their trial run. No participant was allowed to operate the robot in more than one trial.

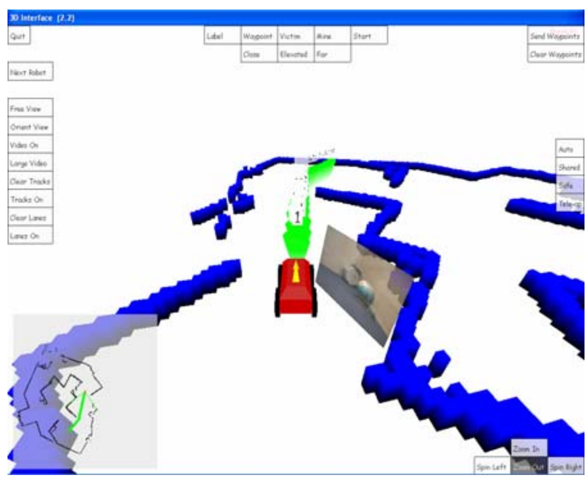

Figure 1 Interface with robot generated map

Prior to each run, a map of the remote environment was created by the robot (Figure 1) such that the participant could correlate the robot's position in its map to an a priori map given as a tool for the assigned task. Each participant was told to direct the robot around the environment and identify items (e.g. dinosaurs, a skull, brass lamp, or building blocks) located at the numbers represented on an a priori map. In addition to identifying items, the participants were instructed to navigate the robot back to the Start/Finish to complete the loop around the remote area. This task was selected because it forced the participants to navigate the robot as well as use the camera controls to identify items at particular points along the path. The items were purposely located in a logical succession in an effort to minimize the affect of differences in the participants' route planning skills.

In addition to the primary task of navigating and identifying objects the participants where asked to simultaneously conduct a secondary task which consisted of answering a series of basic two-digit addition problems on an adjacent computer screen. The participants were instructed to answer the questions to the best of their ability but told that they could skip a problem by hitting the <enter> key if they realized a problem appeared but felt they where too engaged in robot control to answer. Each problem remained present until it was responded to, or the primary task ended. Thirty seconds after a participant's response, a new addition problem would be triggered. The secondary task application recorded time to respond, in seconds, as well as the accuracy of the response and whether the question was skipped or ignored.

During each trial, the interface stored a variety of useful information about the participant's interactions with the interface. For instance, the interface recorded the time to complete the task to be used as a metric of the efficiency between the methods of control. For the CTM participants, the interface also recorded the portion of time the robot was available for direct control. The interface recorded the number of joystick vibrations caused by the participant instructing the robot to move in a direction in which it was not physically possible to move. The number of joystick vibrations represent instances of human navigational error and, in a more general sense, confusion due to a loss of situation awareness. The overall joystick bandwidth was also logged to quantify the amount of joystick usage. Immediately after completing a trial, each participant was asked to rank on a scale of 1 to 10 how "in control" they felt during the operation, where 1 signified "The robot did nothing that I wanted it to do" and 10 signified, "The robot did everything I wanted it to do."

2. RESULTS

All participants completed the assigned task. Analysis of the time to complete the task showed no statistically significant difference between the SSM and CTM groups. On average, SSM participants completed the task slightly faster than their CTM counterparts with M = 308.6 seconds , M = 332.4 seconds, respectively. The difference, however, was not of significance between the sample sets $F(1,31) = 1.758$, $p = 0.139$.

An analysis of human navigational error showed that 81% of participants using CTM experienced no instances of operator confusion as compared to 33% for the SSM participants. Overall, SSM participants logged a total of 59 instances of operator confusion as compared with only 27 for the CTM group. The mean average was 3.93 for the SSM group and 1.59 for the CTM group, although the lack of a Gaussian distribution for either group diminishes the statistical significance of the mean averages or of a standard F test. The median for CTM was 0 as compared with a median of 2 for the SSM mode.

The CTM participants collectively answered 102 math questions, while the SSM participants answered only 58. Of questions answered, CTM participants answered 89.2% correctly as compared to 72.4% answered correctly by participants using SSM. To further assess the ability of SSM and CTM participants to answer secondary task questions an analysis was performed on the average response time for each group. CTM participants had an average response time of 25.1 seconds as compared to 49.2 seconds for those using SSM. This difference was statistically significant $F(1,31) = 2.148$, $p < 0.05$. Together these results indicate that the participants using the collaborative tasking tools experienced a substantial decrease in the required workload to complete the task. In addition, CTM participants enjoyed a higher overall *feeling of control* as compared to SSM participants M = 8.53 and M = 6.73 respectively, $F(1,31) = 3.22$, $p < 0.05$.

4. CONCLUSION

This experiment provides validation of the collaborative tasking tools that have been implemented as part of the Robot Intelligence Kernel. The experiment showed that from an engineering perspective, the blending of guarded motion, reactive obstacle avoidance and global path planning behaviors on board the robot can be used effectively to accomplish a search and detection task. Of greater significance to the Human-Robot Interaction community is the fact that this experiment represents a definitive step away from the supervisory control paradigm where the human may accept or decline robot initiative, while remaining at all times in the leadership role for all task elements. Instead, the collaborative tasking tools presented here arbitrate leadership in a facilitative manner [3] to optimize overall team performance. By constraining operator initiative at the right times, CTM reduces human confusion and frustration. CTM actually increases users' feeling of control by taking control away from them. Although the Human –Robot Interaction community has long used the phrase "mixed initiative" to describe the goal of team members blending their input together. The findings of this paper imply that rather than "mixing" initiative, human-robot teaming may benefit when initiative is "facilitated" to avoid conflict and optimize task allocation.

5. REFERENCES

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